



Industry Research to Address Quasi-Laminar Indications in RPV Forgings

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**NRC PUBLIC MEETING TO DISCUSS POTENTIAL QUASI-LAMINAR
INDICATIONS IN REACTOR PRESSURE VESSEL FORGINGS**

Rockville, MD
March 5, 2013

Agenda

- Fact-finding Visit to Belgium
- Review of Service Experience
- Surveys & Data-gathering
- Planning & Initiation of Generic Analyses
- Future Activities

Fact-finding Visit to Belgium

- World Association of Nuclear Operators (WANO) Paris Office organized a technical conference to inform Industry on the Doel-3 RPV issue
 - “Doel 3 Reactor Vessel Technical Conference Related to the Indications in the Doel 3 Reactor Vessel Revealed by UT-Inspection, 19th September 2012” - Tractebel, Brussels, Belgium
- MRP organized a small Industry team to attend
 - Team members: Anne Demma (EPRI), Greg Selby (EPRI), Mike Turnbow (TVA), Carl Larsen (INPO), Nathan Palm (Westinghouse), Tim Hardin (EPRI), Martin Morra (GE Global Resources)
- Broad attendance by Industry representatives from Europe & Asia

Industry Team Conclusions from Visit

- The hospitality and openness of Electrabel was appreciated
- There were limits to the details that Electrabel was able to share
- Team was concerned that reported UT indications may be over-sized
- Team did not receive any information in visit indicating a generic integrity issue for RPVs
 - However, additional analytical work to resolve unanswered questions was recommended to the MRP and approved (discussed later in this presentation)

Review of Service Experience

Review Service Experience for Quasi-laminar Flaws

- Recent reports released
 - Doel-3 and Tihange-2 Safety Case Reports (Electrabel)
 - Provisional Evaluation Report (Federal Agency for Nuclear Control, FANC)
- Doel-3 and Tihange-2
 - Vessel material and fluence conditions
 - Number of indications
 - Indication size and location
 - Proximity of indications
 - Safety assessment methodology and conclusions

Review Service Experience for Quasi-laminar Flaws

- Objectives of report review:
 - Understand the phenomenon observed at Doel-3 / Tihange-2
 - Assess applicability (if any) to member plants
- Soliciting opinions of metallurgists with expertise and experience in steel-making

Surveys & Data Gathering

Survey and Review of US Plant Data

- October 2012: Issued a survey/questionnaire to all U.S. Pressurized Water Reactors (PWRs) to collect information on forgings
- Objectives of survey:
 - Survey and confirm US vessels with intermediate & lower shell course forgings
 - Confirm fundamental vessel fabrication information
 - Characterize heat treatments
 - Identify forging vendors

Survey and Review of US Plant Data

- 21 operating U.S. PWRs with intermediate & lower shell course forgings
 - 7 other PWRs with nozzle shell course forgings not a concern
- Material/Forging vendors
 - Bethlehem
 - Japan Steel Works
 - Ladish
 - Krupp
 - Klockner-werke
 - SFAC-GF (Creusot-Loire)
 - Rheinstahl-Huttenwerke
 - Rotterdam

Additional Data Collection

- Confirm plant specific material and vessel conditions for US vessels with intermediate & lower shell course forgings
 - Element content
 - Fluence at End of License-Extended (EOLE)
 - Unirradiated properties (e.g., Initial RT_{NDT})
 - Vessel dimensions
- Inputs for planned probabilistic and deterministic analyses

Review of Fabrication NDE Records

- On 2-14-2013, PMMP issued new request to CNOs of PWRs with intermediate & lower shell course forgings
- Requested that fabrication nondestructive examination (NDE) records for the forgings be reviewed
- Information to support bounding generic analyses (described later)

Planning & Initiation of Generic Analyses

Flaw Assessment and RPV Integrity Evaluation

- Flaw assessment and integrity evaluations to demonstrate achievement of safety targets, assuming flaws are present
- Discrete probabilistic and continuum damage mechanics approaches
- Analysis methodologies are appropriate for purpose
- Analysis process is straightforward
 - Define decision and acceptance criteria
 - Select appropriate computational tools
 - Obtain required inputs, e.g., material properties, transient histories, event frequencies

Two Types of Analyses

- Probabilistic Fracture Mechanics (PFM) analysis
- Continuum Damage Mechanics (CDM) analysis

PFM Analyses

- Purpose: Sensitivity studies to assess generic flaw and vessel conditions that would ensure adequate margins against failure for reactor pressure vessels with quasi-laminar degradation in intermediate & lower shell course forgings
- Approach: Use Probabilistic Fracture Mechanics (PFM) to define the conditions where the Through-Wall Cracking Frequency (TWCF) is less than 10^{-6} per operating year
- Conservative representations of the flaw size and location will be used
- The PFM evaluation for embedded quasi-laminar flaws will be consistent with the methodology used by NRC for PTS

CDM Analysis

- Advantageous to have a second analysis using a different methodology: continuum damage mechanics (CDM)
- Deterministic analysis of distributed damage using a multiphase damage model to evaluate vessel integrity (methodology previously used for analysis of fuel cladding failure)
- Define a damage function which serves as a metric for the underlying micro-mechanical process
- This damage function is used to define new constitutive relations which reflect the evolution of damage in the vessel material due to both radiation and hydrogen flaking
- Damage-dependent stress-strain relations are incorporated into a FEA code, which is then used to evaluate vessel integrity under PTS

Future Activities

Planned Future Activities (1/2)

- Revise plan as appropriate for new information learned from review of Electrabel Safety Case reports and at March 5 Public Meeting
- NDE Survey
- Complete PFM Study
- Assess NDE Survey *vis a vis* PFM Study Results
 - Does the PFM study show that risk targets are met for all PWRs with intermediate & lower shell course ring forgings?

Planned Future Activities (2/2)

- Presentation of analytical results
- Support Industry / ASME Code activities as appropriate
- Other activities, as needs are identified

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